BBC RD 1975/8

BBC

RESEARCH DEPARTMENT

1969 1974
THE QUEEN'S AWARD TO INDUSTRY

REPORT

SATELLITE BROADCASTING: the effects of filter design upon the bandwidth and adjacent-channel separation requirements for f.m. television signals

N.H.C. Gilchrist, B.Sc., C.Eng., M.I.E.E.

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION February 1975

BBC RD 1975/8
UDC 621.396.946
621.372.542.2
621.376.3

SATELLITE BROADCASTING: THE EFFECTS OF FILTER DESIGN UPON THE BANDWIDTH AND ADJACENT-CHANNEL SEPARATION REQUIREMENTS FOR F.M. TELEVISION SIGNALS

N.H.C. Gilchrist, B.Sc., C.Eng., M.I.E.E.

Summary

This report describes experimental work which was undertaken to determine the effect of varying the amplitude and group-delay characteristics of the r.f./i.f. filters used in a satellite direct broadcasting f.m. television system. The transmission system assumed employed 13 MHz per volt frequency deviation of the video signal, after pre-emphasis to CCIR standard, and a 6 MHz f.m. sound subcarrier. The work dealt initially with filters at the receiver and at the transmitter, but was extended to cover an investigation into the significance of the sound subcarrier level in determining adjacent-channel separation requirements.

The conclusions drawn from this work are that the receiver filter should be a 4-section type with a bandwidth (to the −3 dB points) of 28 MHz. The only benefit obtainable by group-delay correction of the receiver filter would be a small improvement in the sound channel signal-to-noise ratio. The use of a suitable group-delay corrected filter of about 25 MHz bandwidth at the output of each television transmitter could give a useful degree of protection to a signal in the adjacent channel, but even with such measures it might be necessary to restrict the level of the sound subcarrier accompanying f.m. television transmissions to a peak deviation of ± 2 MHz if planning considerations dictate a channel spacing of 30 MHz or less, with an adjacent-channel protection ratio of −6 dB.

Issued under the authority of

P. Rainger

Head of Research Department

Research Department, Engineering Division.
BRITISH BROADCASTING CORPORATION

February 1975

(EL-102)

SATELLITE BROADCASTING: THE EFFECTS OF FILTER DESIGN UPON THE BANDWIDTH AND ADJACENT-CHANNEL SEPARATION REQUIREMENTS FOR F.M. TELEVISION SIGNALS

N.H.C. Gilchrist, B.Sc., C.Eng., M.I.E.E.

SATELLITE BROADCASTING: THE EFFECTS OF FILTER DESIGN UPON THE BANDWIDTH AND ADJACENT-CHANNEL SEPARATION REQUIREMENTS FOR F.M. TELEVISION SIGNALS

N.H.C. Gilchrist, B.Sc., C.Eng., M.I.E.E.

1. Introduction

Experimental work on the bandwidth and adjacent-channel separation requirements for f.m. television signals is the subject of three BBC Research Department Reports.[1,2,3] In this work, a number of different filters were used to define the intermediate-frequency bandwidth of a f.m. television receiver. Early experiments, to determine bandwidth requirements, used 6-section filters of the type developed by Brown[4] from a method proposed by Cohn,[5] but these suffered from a considerable degree of asymmetry. Furthermore, the Cohn technique was not suitable for constructing filters of relatively high fractional bandwidth. A number of filters were therefore built using separate high-pass and low-pass sections (for reasons of instrumental convenience) in order to simulate bandpass filters using 4 or 6 bandpass sections. By using one more section in the low-pass filter than in the high-pass filter, reasonably good arithmetic symmetry was obtained.

In these earlier studies the amplitude/frequency and group-delay/frequency response characteristics of the filters were measured, but only the amplitude characteristics were compared. Variation of the group-delay across the passband of a filter gives rise to non-linear distortion of a f.m. signal passed by the filter, and the work described in this report was carried out primarily to determine the effect of the group-delay characteristic on system performance and whether or not group-delay correction of filters for f.m. television was worthwhile.

2. Experimental arrangement

2.1 System parameters

The f.m. television signals used in the tests conformed to the recommendations of the European Broadcasting Union, Sub-Group K3. These recommendations suggest that a f.m. television transmission system for direct broadcasting from a satellite should have a deviation of 13 MHz peak-to-peak for a 1-volt video signal after CCIR pre-emphasis,[6] plus a deviation of ±2·8 MHz peak by a f.m. sound subcarrier at or near 6 MHz. All the tests were conducted with a signal level sufficiently high for the effects observed not to be obscured by random noise.

2.2 Equipment

Fig. 1 shows a block schematic diagram of the equipment used. Filter 'A' on this diagram is the receiver

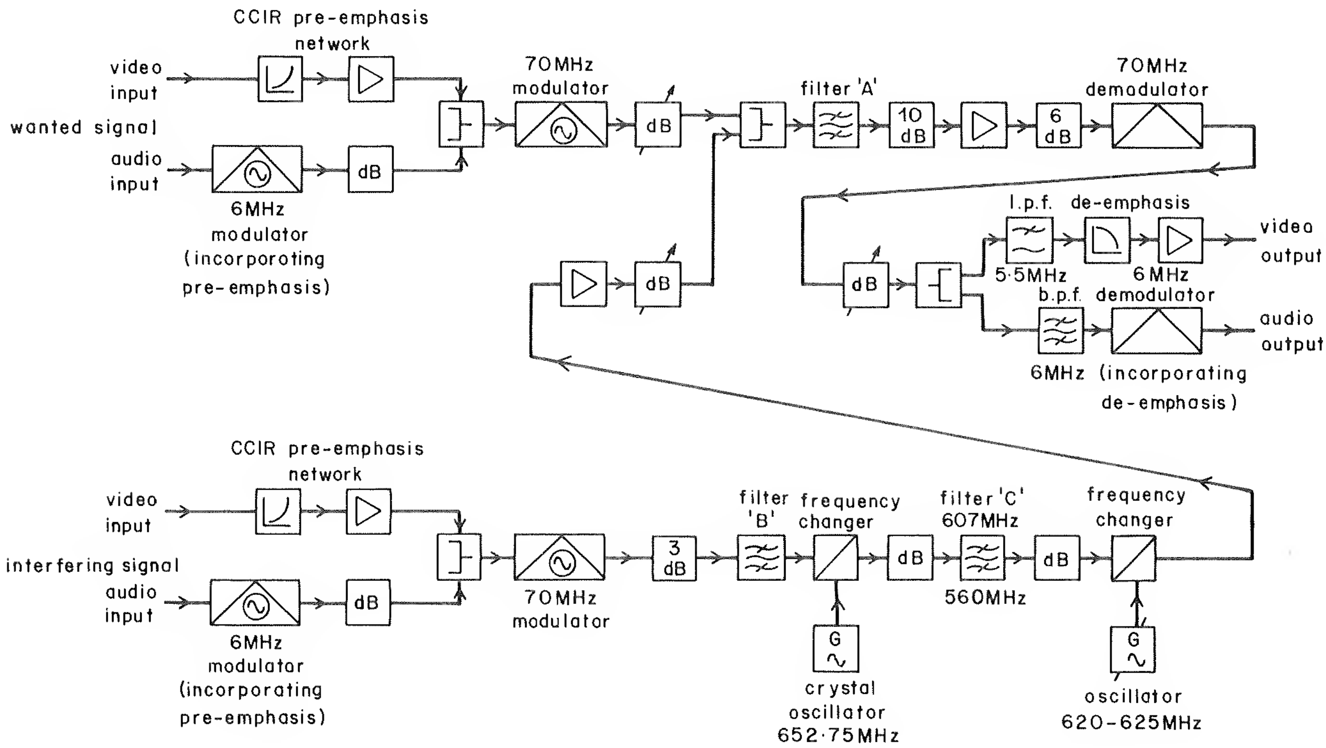

Fig. 1 - Experimental arrangement

filter, and filter 'B' is the output filter of the interfering transmitter.

For tests involving adjacent-channel interference, the interfering signal was produced by a 70 MHz modulator identical with that used for the wanted signal. The frequency of the interfering signal was varied by two frequency-changing processes, and a u.h.f. bandpass filter (filter 'C') removed the image component in the output of the first mixer.

The modulators used in these experiments deviated the carrier to a higher frequency for the sync. pulses and a lower frequency for the highlights of the picture information. The video signal was a.c. coupled.

The filters to be tested were all types comprising separate high-pass and low-pass sections simulating 4 or 6-section bandpass filters. Group-delay equalisers were constructed as separate units so that filters could be tested with or without equalisation, as appropriate. Fig. 2 shows the characteristics of one of the 6-section filters, without equalisation, and Fig. 3 shows the characteristics of one of the 4-section filters with and without group-delay equalisation.

Group-delay correctors were fitted to a number of 4-section filters with bandwidths between 21 and 28 MHz. In all cases, the group-delay variation across the passband of the filter was reduced by about half; from approximately 37 ns to 22 ns.

2.3 Subjective tests

Subjective tests were conducted using technical staff to assess the degree of impairment of colour television pictures, both by bandwidth restriction and by adjacent-channel interference, with the various filters (or combinations of filter plus group-delay equaliser) as filter 'A' in Fig. 1.

Similar subjective tests were also made to determine the effects on adjacent-channel interference of various types of filter in the interfering signal channel (filter 'B' in Fig. 1).

The impairments were judged according to a 6-point scale.*

The non-linear distortion introduced by excessive restriction of the receiver passband raises the level of differential gain and phase distortion of the colour sub-carrier and also introduces a pattern at about 1·57 MHz from beating of the sound and colour subcarrier components. The latter effect becomes objectionable with relatively low levels of non-linearity, lower than those required to make the effects of differential gain and phase distortion apparent on the picture. No measurements of differential gain and phase distortion were made, therefore, and the observers judged the pictures for the impairment due to patterning.

Preliminary subjective tests were used to ascertain which test pictures (for the wanted signal) were the most likely to show the impairments caused by bandwidth restriction and adjacent-channel interference. Previous

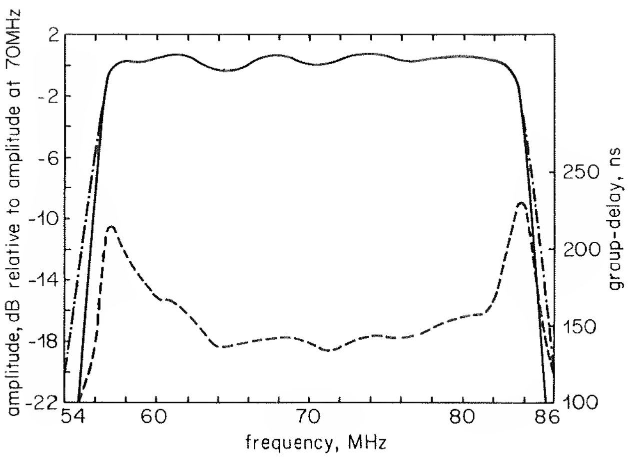

Fig. 2 - Characteristics of 6-section filter

——— *Amplitude/frequency response*
– – – – *Group-delay/frequency response*
–•–• *Calculated response of equivalent 6-section Chebyshev bandpass filter*

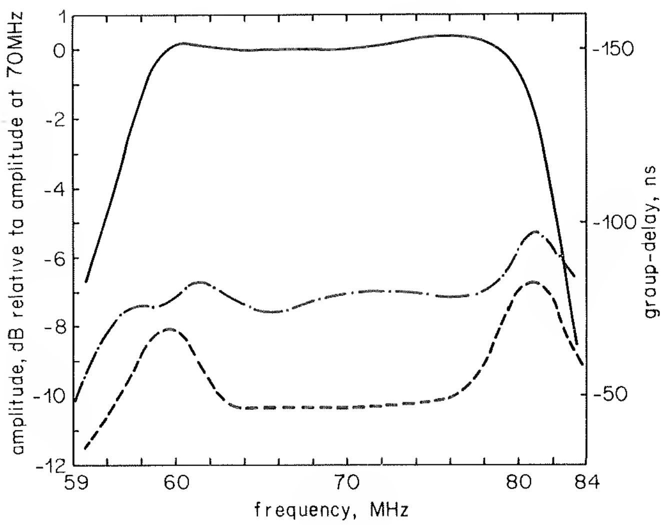

Fig. 3 - Characteristics of 4-section filter

——— *Amplitude/frequency response*
– – – – *Group-delay/frequency response*
–•–• *Group-delay/frequency response of filter + group-delay equaliser*

*The 6-point impairment scale used was that given in CCIR Report 405-1 (New Delhi, 1970) and is as follows:–

1. Imperceptible
2. Just perceptible
3. Definitely perceptible, but not disturbing
4. Somewhat objectionable
5. Definitely objectionable
6. Unusable

Fig. 4 - The slide 'Girl wearing headscarf'

studies[1] had indicated that pictures containing large areas of saturated colour were suitable, and colour bars had been used in this earlier work. In the current work, a caption with a saturated cyan background was found to be even more sensitive to the impairments described. The colour slide 'Girl wearing a headscarf', shown (in monochrome) in Fig. 4, was also used in the adjacent-channel interference tests.

The video information in the interfering signal (where appropriate) was, in all cases, 100% colour bars, as this type of modulation has been found to give the greatest annoyance of any interfering signal. Interfering signals were at a carrier level of + 6dB relative to the level of the wanted signal, and tuned to a lower frequency than the wanted signal (see Section 3.2).

3. Tests using filters without group-delay equalisation

3.1 Impairment caused by bandwidth restriction

Filters simulating 4-section and 6-section bandpass filters were set up to give a number of bandwidths between 21 and 28 MHz. Previous investigations into bandwidth requirements[1] had shown that symmetrically-tuned filters for a f.m. television system with the parameters defined in Section 2.1 would need to have a bandwidth of at least

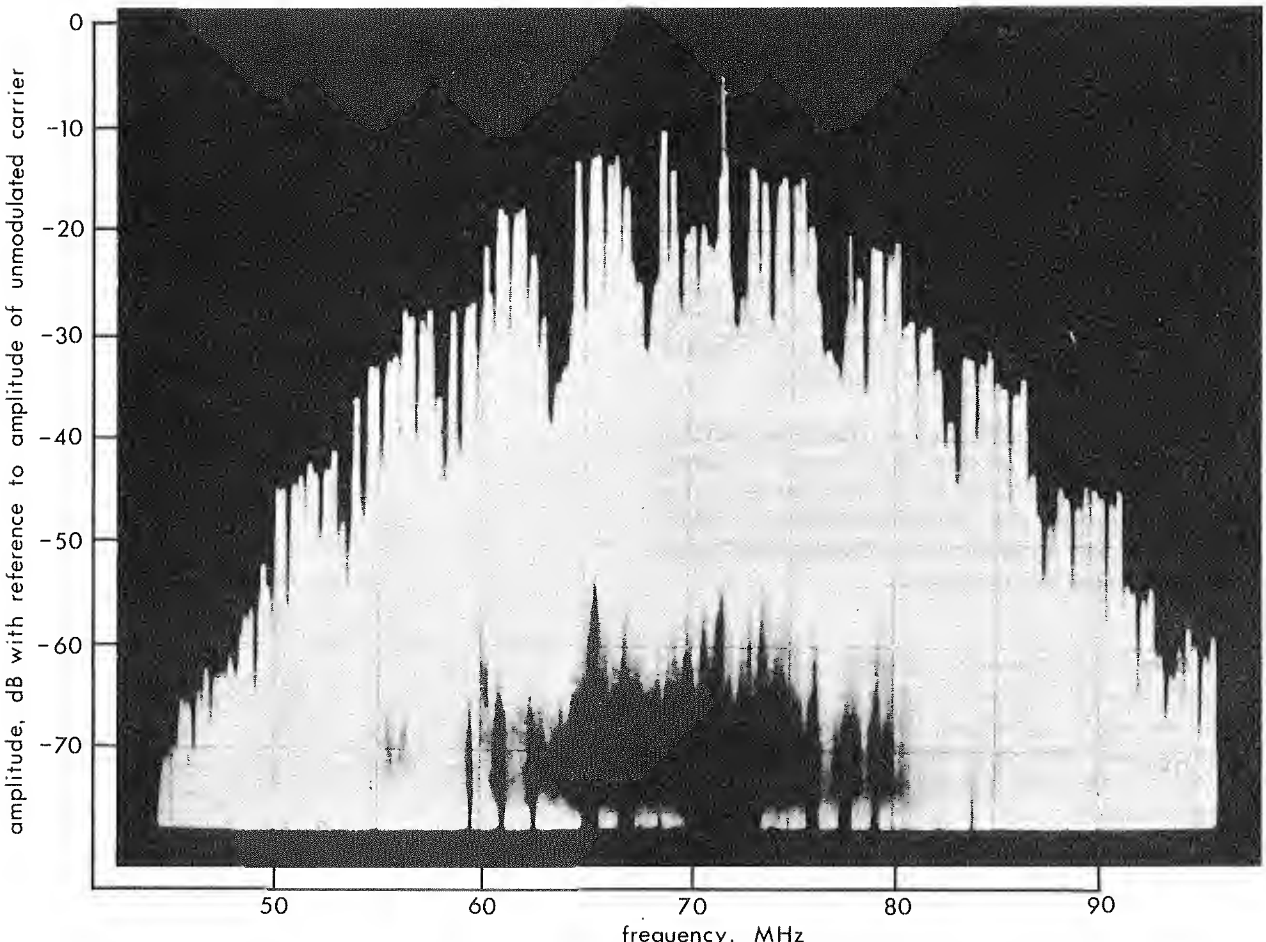

Fig. 5 - Spectrum of f.m. television signal (video modulation: 100% colour bars)

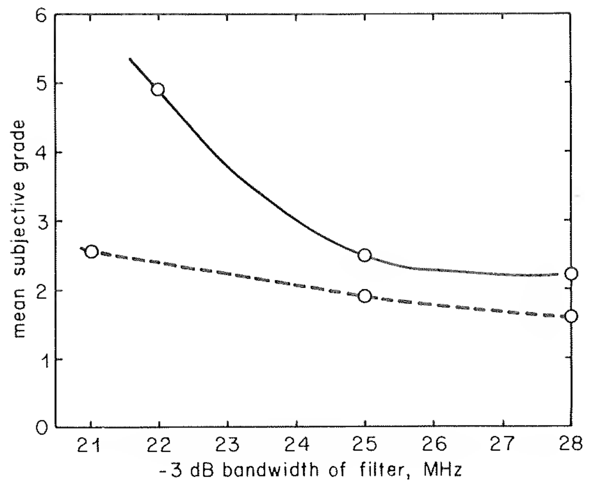

Fig. 6 - Picture impairment caused by bandwidth restriction using filters without group-delay equalisation
——— *6-section filter* - - - - *4-section filter*

28 MHz to the −3 dB points. It was found possible, in the present investigation, to reduce the bandwidth below 28 MHz, without greatly increasing the level of impairment, by offsetting the centre of the filter passband to a point 1·5 MHz below the carrier rest frequency (70 MHz) of the wanted transmission. For subsequent tests, all filters with bandwidths less than 28 MHz were tuned in this way. Fig. 5 shows a photograph of the spectrum of the f.m. television signal. The use of pre-emphasis has, to some extent, reduced spectral asymmetry by attenuating the low-frequency components of the video, but some degree of asymmetry in the region of ±14 MHz remains. The fact that the system would tolerate a more severe restriction of bandwidth on the high-frequency side may be attributable partly to this asymmetry and partly to the fact that non-linear distortion of the synchronising pulses is more tolerable than non-linear distortion of the picture waveform.

The results of subjective tests to determine the minimum acceptable receiver bandwidth in terms of picture impairment are shown in Fig. 6. These results are for tests using colour bars and the cyan-background caption as the wanted signal; normal picture material gives results which are, on average, one grade better.

The effects of bandwidth restriction on the sound channel performance were dealt with in an earlier report.[1] In the current work, a brief test using filters of 28 MHz bandwidth showed that the level of 'buzz-on-sound' was reduced by 2·5 dB when a 6-section filter was replaced by a 4-section type.*

*Sound signal-to-noise ratios were measured with a BBC-modified Niese meter[7] (giving r.m.s. readings for continuous noise) with a CCIR[8] weighting network. The reference signal was 100% modulation, i.e. a deviation of ±50 kHz of the subcarrier, by a 1 kHz tone.

3.2 Impairment caused by adjacent-channel interference

Earlier work[2] had established that a channel separation of 29·5 MHz was suitable for a satellite f.m. television broadcasting system on the assumption that receivers for such a system might have to provide for an adjacent-channel protection ratio of −6 dB, i.e. that they should operate satisfactorily with an adjacent-channel signal up to 6 dB stronger than the wanted signal. This work had also established that the receiver is more sensitive to interference from the adjacent channel towards which the wanted carrier is deviated by picture highlight information. With the sense of modulation used in the experimental equipment this was the lower adjacent channel.

For the present tests, the interfering signal was applied in the lower adjacent channel at a level of +6 dB with respect to the wanted signal, and the impairment grade obtained for a number of frequency separations was assessed by observers for each filter in turn.

Initial tests with symmetrical filters showed that no improvement in adjacent-channel protection was obtained by using a 6-section filter in place of a 4-section one having the same bandwidth between −3 dB points. This confirms a similar finding obtained in the earlier investigation.[2] Since, as shown in Fig. 6, a 4-section filter produces less picture impairment for a given bandwidth that a 6-section type in the absence of interference, all subsequent tests were carried out using 4-section filters.

Taking the results obtained with a symmetrical 28 MHz bandwidth filter as reference, it was found that reducing the bandwidth to 25 MHz with the filter centre frequency offset downwards by 1·5 MHz produced an increase in the sensitivity to lower-adjacent-channel interference. This effect was not investigated but is thought to be due to the increased non-linearity caused by bandwidth restriction producing intermodulation between wanted and interfering signal components.

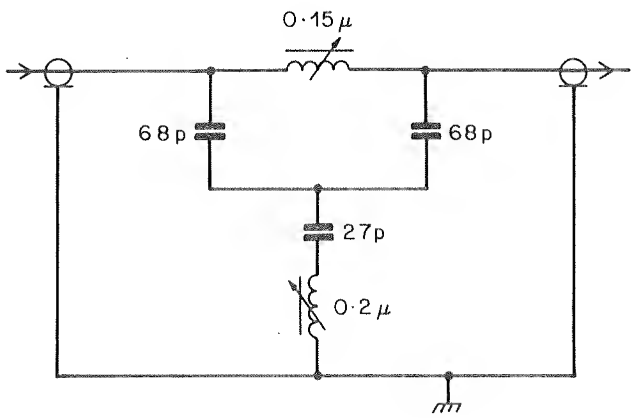

Fig. 7 - Circuit diagram: group-delay corrector

The filter in the output of the interfering transmitter, filter 'B', was a 4-section type with a −3 dB bandwidth of 28 MHz, symmetrical about the carrier rest frequency.

4. Tests using filters with group-delay equalisation

4.1 Impairment caused by bandwidth restriction

A number of single-section group-delay equalisers were constructed, one for use with each of the 4-section filters tested. The equalisers took the form of the circuit shown in Fig. 7. This type of circuit is an all-pass network, with a flat amplitude/frequency characteristic.

Subjective tests were conducted using 8 observers to assess the level of impairment of the f.m. television signal when it was passed through a number of filters with and without group-delay equalisation. As in the case of Fig. 6, the impairment observed was patterning due to the 1·57 MHz beat between the sound and chrominance components of the signal. The results, given in Fig. 8, show that group-delay equalisation gives up to ¾ grade improvement at receiver bandwidths below 28 MHz. A cyan caption (white letters on a cyan background) was used as the wanted picture for these tests.

With a 28 MHz-bandwidth filter, group-delay equalisation produced a reduction 4 dB in the level of sound buzz caused by interference on the sound channel from the vision signal. This would give a resultant sound signal-to-noise ratio of 54·5 dB (weighted) as measured with the BBC-modified Niese meter and CCIR weighting network.

4.2 Impairment caused by adjacent-channel interference

Similar tests to those described in Section 3.2 were made using group-delay corrected filters.

As in the tests without group-delay correction, it was found that replacing a 28 MHz symmetrically-tuned filter by a 25 MHz asymmetrically-tuned one increased the sensitivity to adjacent-channel interference and results obtained with the 25 MHz filter were, in general, one grade worse than those obtained with the 28 MHz filter. A further reduction of bandwidth to 23 MHz gave no improvement over 25 MHz.

5. Tests with various filters in the output of the interfering transmitter

The tests described in Sections 3 and 4 have shown that the use of a 25 MHz offset-tuned filter in the receiver gives no advantage in interference rejection over a symmetrically-tuned 28 MHz bandwidth filter. On the other hand, the use of an asymmetric filter *at the transmitter* to restrict the spectrum of the upper sideband components might reduce interference to the signal in the upper adjacent-channel. The results shown in Fig. 8 already indicate that it would be acceptable to pass the signal through a filter narrower than 28 MHz. A series of subjective tests was therefore conducted to compare the effects of two different filters used in the output of the interfering transmitter. A 28 MHz bandwidth symmetrically-tuned filter was used for the first test, and an asymmetrical 25 MHz filter (with −3 dB points at 56 and 81 MHz) was used for the second test. The receiver filter was a 4-section type, symmetrically-tuned with 28 MHz bandwidth.

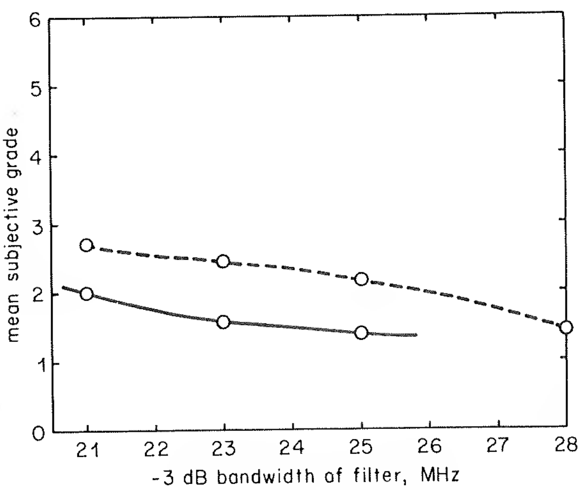

Fig. 8 - Picture impairment caused by bandwidth restriction using filters with and without group-delay equalisation
——— *Result for 4-section filter with group-delay equaliser*
– – – – *Result for 4-section filter without group-delay equaliser*

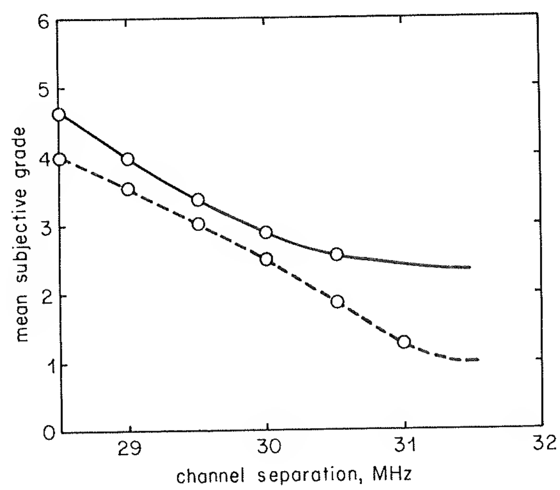

Fig. 9 - Effect of asymmetrical filtering of the adjacent-channel signal on the impairment of the wanted signal
——— *Result obtained with 28 MHz-bandwidth symmetrical filter in output of interfering transmitter*
– – – – – *Result obtained with 25 MHz-bandwidth asymmetrical filter in output of interfering transmitter*
(Adjacent-channel signal 6 dB stronger than wanted signal)

The colour slide 'Girl wearing a headscarf' and a caption on a saturated cyan background were the signals used for the wanted pictures. The results obtained with the colour slide showed good agreement with data obtained previously.[2] The caption signal was much more sensitive than the slide to the effects of adjacent-channel interference, and the results presented in Fig. 9 were obtained using this signal. These results show that an improvement is obtained when the 25 MHz bandwidth, asymmetrically-tuned filter is used instead of the 28 MHz bandwidth filter in the output of the interfering transmitter.

6. Tests with reduced level of sound subcarrier

The results of Fig. 9 imply that, on the basis of a protection ratio of −6 dB, a separation of rather more than 30 MHz is required between adjacent channels; previous work,[2] not involving tests with the saturated-colour-background signal, had indicated that 29·5 MHz separation would be sufficient. Some further tests were conducted, therefore, with the sound subcarrier level reduced by 3 dB on both the wanted and interfering signals (i.e. the deviation of the carrier by the subcarrier was reduced by 3 dB). These tests showed that, with the reduced level of sound subcarrier, the same subjective grades could be achieved with channel separations 1·5 MHz less than those shown in Fig. 9. This means that a channel separation of 30 MHz would be quite adequate with a −6 dB protection ratio for transmissions with the reduced level of sound subcarrier, even with the most demanding type of picture.

7. Conclusions

An experimental investigation has been carried out into the effects of the characteristics of the bandwidth-defining filters in a f.m. television system conforming to the 1973 recommendations of EBU Sub-Group K3, namely 13 MHz/volt deviation for the video signal with a 6 MHz f.m. sound subcarrier producing ±2·8 MHz peak deviation.

As far as the i.f. filters in domestic receivers are concerned (assuming that these are of the conventional lumped-constant type) the optimum design is a four-section filter with a bandwidth of 28 MHz centred on the carrier rest-frequency. The addition of a single-section group-delay corrector, which approximately halves the group-delay error of the basic filter, permits the bandwidth of the i.f. filter to be reduced but this does not give any advantage in terms of increased immunity to adjacent-channel interference. However, a worthwhile benefit obtained by this measure of group-delay equalisation was found to be an improvement of 4 dB in the sound-channel signal-to-noise ratio, obtained under strong-signal conditions due to the reduction of the interfering buzz on sound from the vision signal.

The use of group-delay corrected, asymmetrically tuned filter at the output of the transmitter does, however, reduce the level of interference caused to an adjacent-channel transmission. With the relatively modest degree of group-delay correction used in the tests it was found possible to use a transmitter filter of 25 MHz bandwidth, off-tuned by 1·5 MHz, and this reduced the subjective effect of interference to the upper adjacent channel by about one-half grade.

The amount of group-delay equalisation used in the work described in this report was limited to that achieved by simple, single-section correctors of the type thought to be economically practicable in domestic receivers.

For transmitter filters a much higher degree of correction is possible. For domestic receivers, it may well be that surface-wave filters will be in common use in i.f. circuits by the time that direct satellite broadcasting is instituted and with such filters the intrinsic group delay can be sensibly constant, not only over the pass band but also over the flanks of the amplitude response. The benefits that might be obtainable by exploiting the characteristics of these filters, both in the reduction of interference and in the general improvement of system performance, e.g. sound signal-to-noise ratio, merit further investigation, but the results would not be likely to affect the broad conclusions concerning adjacent-channel interference protection.

Previous work on satellite television broadcasting[2,3] had indicated that a channel separation of 29·5 MHz would be satisfactory for a system with the parameters suggested by EBU Sub-Group K3. The work described in this report has shown that, if it is required to protect against adjacent-channel interference at a 6 dB higher level than that of the wanted signal, with the most demanding type of pictures, the use of a channel spacing of 30 MHz or less may require the magnitude of the sound subcarrier to be reduced by 3 dB.

8. References

1. GILCHRIST, N.H.C. 1973. Satellite Broadcasting: bandwidth requirements for f.m. television signals. BBC Research Department Report No. 1973/19.

2. GILCHRIST, N.H.C. 1974. Satellite Broadcasting: channel separation requirements for f.m. television signals. BBC Research Department Report No.1974/20.

3. GILCHRIST, N.H.C. 1974. Satellite Broadcasting: channel separation requirements for f.m. sound signals, and for a f.m. sound signal adjacent to a f.m. television signal. BBC Research Department Report No. 1974/21.

4. BROWN, K.E. 1964. Systematic development of Cohn structure for h.f. band-pass filters. Electronic Engineering, July 1964, **36**, 437, pp. 448–452.

5. COHN, S.B. 1954. Direct-coupled-resonator filters. *Proc., I.R.E.* February 1954, **45**, 2, pp. 187–196.

6. CCIR Recommendation 405-1, XIIth Plenary Assembly (New Delhi, 1970), Vol. IV, Part 1, p. 148, Curve B (625 lines).

7. GEDDES, W.K.E. 1968. The assessment of noise in audio-frequency circuits. BBC Research Department Report No. EL-17, Serial No. 1968/8. See CCIR Document 10/175 (Period 1970–1974) also issued as CMTT/141.

8. CCIR Recommendation 468, XIIth Plenary Assembly (New Delhi, 1970), Vol. V, Part 1, p. 227.

CLA/AMM

Printed by BBC RESEARCH DEPARTMENT, Kingswood Warren, Tadworth, Surrey, KT20 6NP